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Non-BPS D-brane Solutions in Six Dimensional Orbifolds

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Abstract

Starting with the non-BPS D0-brane solution of IIB$/(-1)^{F_L} I_4$ constructed recently by Eyras and Panda we construct via T-duality the non-BPS D2-brane and D1-brane solutions of IIB$/(-1)^{F_L} I_4$ and IIA$/(-1)^{F_L} I_4$ predicted by Sen. The D2-brane couples magnetically to the vector field of the NS5B-brane living in the twisted sector of the Type IIB orbifold, whereas the D1-brane couples (electrically and magnetically) to the self-dual 2-form potential of the NS5A-brane that is present in the twisted sector of the Type IIA orbifold construction. Finally we discuss the eleven dimensional interpretation of these branes as originating from a non-BPS M1-brane solution of M-theory orientifolded by $\Omega_\rho I_5$.

1 Introduction and Summary

The study of brane-antibrane systems in string and M-theory has brought a new perspective onto the understanding of non-perturbative extended objects (see [1]-[4], and references therein). BPS branes arise as by-products when the tachyonic mode of the open strings connecting the brane and the antibrane condenses in a vortex-like configuration. Also, one can deduce in this framework the presence of new non-BPS extended objects when the tachyon condenses, instead, in a kink-like configuration. These objects have subsequently been shown to play a key role in testing string dualities beyond the BPS level. In Type II and M-theory they are however unstable, because the open strings ending on them contain real tachyonic excitations, but the instability can be cured when the theory is projected out by a certain symmetry that removes the tachyons from the spectrum. This happens in particular for some non-BPS branes in Type I and in certain orbifold/orientifold constructions of Type II and M-theory.

An interesting and still open problem is the construction of the supergravity solutions corresponding to these non-BPS branes. In the Type II theories given that they are unstable one does not expect to find stable classical solutions of the supergravity that could be associated to these branes. Only in some cases it has been possible to construct stable solutions, like the one corresponding to a Kaluza-Klein monopole-antimonopole pair in M-theory, that is stabilized by suspending the system in an external magnetic field (see [5] and [6, 7, 8, 9, 10] for related work), or the solution of the, unstable, non-BPS D-instanton of Type IIA constructed in [11]. For the stable non-BPS branes one however expects to find solutions of the supergravity equations of motion that describe these branes in the strong coupling regime.

Recently, using the boundary state formalism, Eyras and Panda [12] found the asymptotic behavior of the solution corresponding to the non-BPS D0-brane of the Type IIB theory orbifolded by $(-1)^{F_L} I_4$ [13, 14][1]. This theory is S-dual to Type IIB orientifolded by ΩI_4, Ω being the worldsheet parity reversal operation. The twisted sector of this orientifold construction of Type IIB consists on 16 O5 orientifold fixed planes together with a D5-brane on top of each plane, therefore it carries an SO(2) vector potential. This theory contains massive non-BPS states in the perturbative spectrum arising from open strings stretched between a D5-brane and its image [15]. These states are stable, since they are charged under the SO(2) gauge field of the twisted sector, and correspond in the strong coupling limit to the

[1]Here F_L denotes the left-moving spacetime fermion number, and $I_4 : x^i \to -x^i\,; i = 1, \ldots 4$.

non-BPS D0-branes of IIB/$(-1)^{F_L} I_4$ [13, 14]. These non-BPS D0-branes are also charged with respect to the SO(2) vector field of the, S-dual, twisted sector, and this renders them stable. Moreover, for a critical value of the radii of the compact orbifold a pair of branes satisfies a no force condition [16], and this allows to pile up a number of them. This opens the possibility of constructing solutions corresponding to a large number of parallel non-BPS D0-branes, which could correctly describe the weak coupling regime of the theory. More importantly for our discussion, it is possible to construct infinite arrays of non-BPS D0-branes, from where one can derive other non-BPS D-brane solutions via T-duality transformations.

In this paper we concentrate on this and other stable non-BPS branes, that occur in the six dimensional orbifold/orientifold constructions obtained by projecting out the Type IIB theory by ΩI_4 and duality-related operations. In particular, we focus on the Type IIB and Type IIA theories divided out by $(-1)^{F_L} I_4$. The $(-1)^{F_L}$ operation is identified in the strong coupling limit as the transformation reversing the orientation of open D-strings (D2-branes) in the Type IIB (Type IIA) theory, as implied by its connexion via S-duality with the Ω symmetry of Type IIB [17] (in Type IIA a further T-duality transformation is required). Therefore, the twisted sector of Type IIB/$(-1)^{F_L} I_4$ can be described non-perturbatively as 16 O5-NS5B systems [18, 19], and that of Type IIA/$(-1)^{F_L} I_4$ as the same number of O5-NS5A systems [18]. An O5-plane with a NS5-brane on top of it contains an SO(2) gauge field associated to open D-strings ending on the NS5-brane[2], and the non-BPS D0-branes are charged with respect to this twisted field. In the Type IIA theory, the O5-NS5A system contains a self-dual 2-form field associated to open D2-branes ending on the NS5A-brane, and therefore the twisted sector contributes with an SO(2) self-dual 2-form potential[3].

In [1] Sen conjectured that together with the non-BPS D0-brane, coupled electrically to the SO(2) vector field of the NS5B-O5 system, there is a non-BPS D2-brane, placed on the orbifold plane, that couples magnetically to the same vector field, and arises from open D3-branes stretched between a NS5B-brane and its mirror. Also, T-duality predicts a non-BPS D1-brane in IIA/$(-1)^{F_L} I_4$ located on an orbifold plane, which should couple, electrically and magnetically, to the self-dual 2-form potential of the twisted sector, and arise from open D2-branes stretched between a NS5A-brane and its mirror.

In this note we construct these D-brane solutions. We also show that there is a non-BPS M1-brane solution of M-theory orientifolded by $\Omega_\rho I_5$

[2]Note that in the non-perturbative resolution of the orbifold fixed plane, its U(1) gauge symmetry is broken to SO(2), since this is the gauge field corresponding to the O5-NS5B, as implied by its S-duality with the O5-D5 system.

[3]See [18] and [20, 21] for the detailed description of the twisted sector.

[20, 21], where Ω_ρ reverses the orientation of the M2-brane, to which all these branes are related by reduction and dualities. This provides a unifying picture within M-theory of the stable non-BPS branes that occur in the six dimensional orbifold/orientifold constructions related to $\Omega_\rho I_5$.

M-theory orientifolded by $\Omega_\rho I_5$ contains a twisted sector that can be identified as a system of 32 O5 orientifold fixed planes with one M5-brane located on top of each plane, in order to cancel its charge. This theory contains non-BPS M1-branes that arise from open M2-branes stretched between an M5-brane and its mirror [15]. They couple, electrically and magnetically, to the self-dual 2-form potential living in the M5-brane, what makes them stable. In reducing to the Type IIA theory one can consider two possibilities:

1. Reduce along a worldvolume direction of the M5-O5 system. In this case one obtains Type IIA orientifolded by ΩI_5, whose twisted sector can be interpreted as 32 D4-O4 systems. This theory contains perturbative massive non-BPS states, which can be interpreted in M-theory as non-BPS M1-branes wrapped on the eleventh direction [15], as well as non-perturbative non-BPS strings coming from open D2-branes stretched between a D4-brane and its mirror, which correspond to unwrapped M1-branes in M-theory [1]. T-duality along one of the orbifolded directions gives then rise to the Type IIB theory orientifolded by ΩI_4, whose twisted sector is described by 16 D5-O5 systems. This theory contains perturbative non-BPS particle states and non-perturbative non-BPS 2-branes, connected by T-duality with the non-BPS objects of IIA.

2. Reduce M-theory/$\Omega_\rho I_5$ along one of the orbifolded directions. In this case one obtains Type IIA projected out by $(-1)^{F_L} I_4$, with a twisted sector consisting of 16 NS5-O5 systems. The non-BPS M1-brane gives rise to a non-BPS D1-brane in IIA that couples (electrically and magnetically) to the self-dual 2-form potential living in the worldvolume of the NS5A-O5. Now T-duality along a worldvolume direction of the NS5A-O5 maps the theory onto Type IIB divided by $(-1)^{F_L} I_4$, with a twisted sector identified as 16 NS5-O5 systems. Non-BPS D0-branes are coupled electrically to the SO(2) vector field of the twisted sector, and non-BPS D2-branes magnetically. These branes are related to the non-BPS D1-brane by T-duality.

Consistently with the whole duality picture [22], the two theories that are obtained by either reducing along an M5-brane direction and then T-dualizing along a transverse direction, or viceversa, are related by S-duality. In particular one obtains IIB/ΩI_4 and IIB/$(-1)^{F_L} I_4$ respectively. We also see that the non-BPS M1-brane of M-theory/$\Omega_\rho I_5$ is the eleven dimensional origin of the non-BPS branes that can be defined in the Type II orbifolds/orientifolds obtained by reduction.

2 The non-BPS D0-brane solution of [12]

The asymptotic behavior of the solution corresponding to the non-BPS D0-brane of Type IIB orbifolded by $(-1)^{F_L} I_4$ has been derived in [12] using the boundary state formalism. In this formalism one can compute the long distance behavior of the massless fields generated by the D-brane and predict in this manner the asymptotic behavior of the corresponding classical solution [23]. A pair of non-BPS D0-branes satisfies a no-force condition when the orbifold is compactified to a particular critical value of the radii [16]. When this happens it is possible to construct periodic infinite arrays of non-BPS D0-branes and compute T-dual solutions, which is what we shall be doing in the next sections.

The asymptotic form of the solution of [12], corresponding to a D0-brane situated at one of the fixed points of the orbifold, reads, in string frame[4]:

$$
\begin{aligned}
ds^2_{D0} &= -(1 - \frac{1}{3}\frac{\kappa_6 T_0}{2\pi^2\Omega_4}\frac{1}{|y|^3} + \ldots)dt^2 + \\
&\quad +(1 + \frac{1}{3}\frac{\kappa_6 T_0}{2\pi^2\Omega_4}\frac{1}{|y|^3} + \ldots)\delta_{mn}dy^m dy^n + \\
&\quad +g_{ij}(y)dx^i dx^j\,;\; m,n = 1,\ldots 5\,;\; i,j = 1,\ldots 4\,, \\
e^{\phi} &= 1 + \frac{1}{2}\frac{\kappa_6 T_0}{2\pi^2\Omega_4}\frac{1}{|y|^3} + \ldots\,, \\
C_0^{(1)} &= -\frac{1}{3}\frac{\kappa_6 Q_0}{\sqrt{2}\Omega_4}\frac{1}{|y|^3} + \ldots\,.
\end{aligned}
\tag{2.1}
$$

Here we have taken $\alpha' = 1$ but otherwise the notation is that in [12]. Namely, $\kappa_D^2 = 8\pi G_D$, $\kappa_{D-d}^2 = \kappa_D^2/V_d$, with V_d the volume of the d dimensional space, Ω_4 is the area of a unit sphere surrounding the D0-brane, T_0 is the tension of

[4] In [12] a somewhat more general solution depending on a free parameter a is given, derived by impossing the no-force condition of a pair of branes at the critical radii as a constraint for the background fields. Here we have chosen to work with the strictly linearized solution, though the same kind of generalization can be done for our solutions.

the brane, Q_0 its charge[5], y^m, $m = 1, \dots 5$ the longitudinal directions along the NS5B-O5 worldvolume, and x^i, $i = 1, \dots 4$, the transverse, orbifolded directions. The critical value of the radii: $R_c = 1/\sqrt{2}$, has already been substituted in the solution. $C^{(1)}$ is the vector potential coming from the twisted sector, under which the D0-brane is charged.

As discussed in [12] the components of the metric associated to the orbifolded directions cannot be inferred from the boundary state formalism. We will see however in the last section that it is possible under certain assumptions about the symmetry of the solutions to infer their asymptotic behavior.

3 The non-BPS D1-brane of IIA/$(-1)^{F_L} I_4$

Considering a periodic infinite array of non-BPS D0-branes along the y^5 direction we can construct via T-duality a non-BPS D1-brane solution in the Type IIA theory projected out by $(-1)^{F_L} I_4$. This brane is situated at one of the fixed points of the orbifold with its worldsheet extended along the non-compact spacetime. We find:

$$
\begin{aligned}
ds^2_{D1} &= (1 - \frac{\kappa_6 T_1}{4\pi^2\Omega_3}\frac{1}{|y|^2} + \dots)(-dt^2 + d\sigma^2) + \\
&\quad +(1 + \frac{\kappa_6 T_1}{4\pi^2\Omega_3}\frac{1}{|y|^2} + \dots)\delta_{mn} dy^m dy^n + g_{ij}(y) dx^i dx^j \, ; \\
&\quad m, n = 1, \dots 4\, ;\ i, j = 1, \dots 4\, , \\
e^{\phi} &= 1 + \frac{\kappa_6 T_1}{4\pi^2\Omega_3}\frac{1}{|y|^2} + \dots\, , \\
C^{(2)}_{0\sigma} &= \frac{1}{2}\frac{\kappa_6 Q_1}{\sqrt{2}\Omega_3}\frac{1}{|y|^2} + \dots\, .
\end{aligned}
\tag{3.1}
$$

Here T_1 is the tension of the brane, Q_1 its charge and Ω_3 the area of the unit 3-sphere surrounding the string. The twisted sector consists on a 2-form potential, under which the D1-brane is charged. T-duality implies that this field is to be interpreted as the 2-form potential living in a O5-NS5A system.

This D1-brane solution can be interpreted as a ten dimensional 1-brane located at the origin of the four-dimensional compact space. Considering first

[5] Impossing open-closed string consistency for boundary states, T_0 and Q_0 are fixed to: $T_0 = 8\pi^{7/2}$, $Q_0 = 8\sqrt{2}\pi^{3/2}$, (see [12]).

a single compactified direction, a 1-brane sitting at the origin of the S^1 can be seen from the point of view of the covering space of the S^1 as an equally spaced array of D1-branes in the S^1 direction. If $\vec{x}$ denotes a vector in the full nine dimensional transverse space, we can then approximate[6] $1/|x|^6$ by a sum $\sum_{n \in Z} 1/(r^2 + (x^9 - 2\pi n R_9)^2)^3$, with $r^2 = \sum_{m=1}^4 y^m y_m + \sum_{i=1}^3 x^i x_i$, and, assuming that the size of the compact direction is smaller than the distance in the non-compact space, we can further approximate the sum by an integral. Repeating this process for the four compact directions we can finally write (see for instance [24] for more details):

$$\frac{1}{|y|^2} \sim \frac{1}{|x|^6} \Pi_{i=1}^4 (2\pi R_i)(I_1 I_2 I_3 I_4)^{-1} , \tag{3.2}$$

where R_i are the radii of the compactified orbifold and $I_n \equiv \int_0^\pi d\theta \sin^n \theta$. Substituting back in the expression for the D1-brane solution in the compact orbifold we can then obtain the corresponding solution in the uncompactified case:

$$\begin{aligned}
ds^2_{D1} &= (1 - \frac{1}{6}\frac{\kappa_{10} T_1}{\Omega_7}\frac{1}{|x|^6} + \ldots)(-dt^2 + d\sigma^2) + \\
&\quad +(1 + \frac{1}{6}\frac{\kappa_{10} T_1}{\Omega_7}\frac{1}{|x|^6} + \ldots)\delta_{mn} dy^m dy^n + g_{ij} dx^i dx^j ; \\
&\quad m, n = 1, \ldots 4 ; \; i, j = 1, \ldots 4 , \\
e^\phi &= 1 + \frac{1}{6}\frac{\kappa_{10} T_1}{\Omega_7}\frac{1}{|x|^6} + \ldots , \\
C^{(2)}_{0\sigma} &= \frac{1}{2}\frac{\kappa_6 Q_1}{\sqrt{2}\Omega_3}\frac{1}{|y|^2} + \ldots .
\end{aligned} \tag{3.3}$$

Now Ω_7 is the area of the unit 7-sphere surrounding the string. The expression for the 2-form potential is the same as in the compactified case since it lives in the twisted sector. In [12] it is shown that for the non-BPS D0-brane this kind of approach in order to relate the uncompactified and the compactified solutions gives the same answer than the boundary state analysis of the uncompactified orbifold. This should be the case also for the D1-brane.

It is straightforward to check that the D1-brane solution solves the equations of motion derived from an action $S_{\text{untwisted}} + S_{\text{twisted}}$, where:

[6]The choice of this function will be clear below.

$$S_{\rm untwisted} = \frac{1}{2\kappa_{10}^2} \int d^{10}x\, e^{-2\phi} \sqrt{|{\rm det} g|} \left(R + 4(\partial\phi)^2 \right) , \tag{3.4}$$

and the action corresponding to the twisted sector is proportional to the action associated to a pair NS5A-O5. This reads, in string frame and to first order in α':

$$\begin{aligned} S_{\rm twisted} &\sim \int d^6y \sqrt{|{\rm det} g|} \left(1 + (\mathcal{H}^{(3)})^2 + \ldots \right) - \int d^6y \sqrt{|{\rm det} g|} = \\ &= \int d^6y \sqrt{|{\rm det} g|} (\mathcal{H}^{(3)})^2 + \ldots . \end{aligned} \tag{3.5}$$

Here $\mathcal{H}^{(3)}$ is the field strength associated to the self-dual 2-form potential of the NS5A-brane, with the self-duality condition impossed at the level of the equations of motion, and the metric is restricted to the position of the orientifold fixed plane.

4 The non-BPS D2-brane of $IIB/(-1)^{F_L} I_4$

Performing now a T-duality transformation of the D1-brane solution along the y^4 direction we obtain a D2-brane solution of $IIB/(-1)^{F_L} I_4$. This brane is located at one of the fixed points of the orbifold, with its worldvolume extending along the non-compact spacetime. Taking the non-BPS D1-brane in the compactified orbifold at the critical radii, where it is possible to construct periodic infinite arrays of strings since they satisfy a no-force condition, and applying the T-duality rules we find:

$$\begin{aligned} ds^2_{D2} &= (1 - \frac{\kappa_6 T_2}{2\pi^2 \Omega_2} \frac{1}{|y|} + \ldots)(-dt^2 + d\sigma_1^2 + d\sigma_2^2) + \\ &\quad + (1 + \frac{\kappa_6 T_2}{2\pi^2 \Omega_2} \frac{1}{|y|} + \ldots) \delta_{mn} dy^m dy^n + g_{ij}(y) dx^i dx^j \,; \\ &\quad m,n = 1, \ldots 3\,;\ i,j = 1, \ldots 4\,, \\ e^{\phi} &= 1 + \frac{\kappa_6 T_2}{4\pi^2 \Omega_2} \frac{1}{|y|} + \ldots , \\ C^{(3)}_{0\sigma_1\sigma_2} &= -\frac{\kappa_6 Q_2}{\sqrt{2}\Omega_2} \frac{1}{|y|} + \ldots . \end{aligned} \tag{4.1}$$

Here T_2 is the tension of the brane, Q_2 its charge and Ω_2 the area of the unit 2-sphere surrounding the 2-brane.

The same analysis of the previous section gives the following form for the solution in the uncompactified case:

$$
\begin{aligned}
ds^2_{D2} = & (1 - \frac{1}{5}\frac{\kappa_{10}T_2}{\Omega_6}\frac{1}{|x|^5} + \ldots)(-dt^2 + d\sigma_1^2 + d\sigma_2^2) + \\
& +(1 + \frac{1}{5}\frac{\kappa_{10}T_2}{\Omega_6}\frac{1}{|x|^5} + \ldots)\delta_{mn}dy^m dy^n + g_{ij}dx^i dx^j\,; \\
& m,n = 1,\ldots 3\,;\ i,j = 1,\ldots 4\,, \\
e^{\phi} = & 1 + \frac{1}{10}\frac{\kappa_{10}T_2}{\Omega_6}\frac{1}{|x|^5} + \ldots\,, \\
C^{(3)}_{0\sigma_1\sigma_2} = & -\frac{\kappa_6 Q_2}{\sqrt{2}\Omega_2}\frac{1}{|y|} + \ldots\,.
\end{aligned}
\tag{4.2}
$$

Now Ω_6 is the area of the unit 6-sphere surrounding the membrane.

This brane is electrically charged with respect to the 3-form potential of the NS5B-O5 system, or equivalently, magnetically charged with respect to its vector potential. Therefore, it solves the equations of motion derived from $S_{\text{untwisted}} + S_{\text{twisted}}$, with:

$$
\begin{aligned}
S_{\text{twisted}} \sim & \int d^6y\sqrt{|\text{det}g|}\left(1 + (\tilde{\mathcal{F}}^{(4)})^2 + \ldots\right) - \int d^6y\sqrt{|\text{det}g|} = \\
= & \int d^6y\sqrt{|\text{det}g|}(\tilde{\mathcal{F}}^{(4)})^2 + \ldots\,,
\end{aligned}
\tag{4.3}
$$

where we have dualized the vector field of the NS5B-brane onto a 3-form potential with field strength $\tilde{\mathcal{F}}^{(4)}$, and the metric is restricted to the position of the orientifold fixed plane.

5 The non-BPS M1-brane of M-theory/$\Omega_\rho I_5$

Oxidizing the D1-brane solution of the Type IIA theory on the orbifold we can obtain the expression for a stable M1-brane solution of M-theory orientifolded by $\Omega_\rho I_5$:

$$
d\hat{s}^2_{M1} = (1 - \frac{5}{18}\frac{\kappa_{10}T_1}{\Omega_7}\frac{1}{|x|^6} + \ldots)(-dt^2 + d\sigma^2) +
$$

$$+(1+\frac{1}{8}\frac{\kappa_{10}T_1}{\Omega_7}\frac{1}{|x|^6}+\ldots)\delta_{mn}dy^m dy^n +$$

$$+(1-\frac{1}{9}\frac{\kappa_{10}T_1}{\Omega_7}\frac{1}{|x|^6}+\ldots)g_{ij}dx^i dx^j + (1+\frac{2}{9}\frac{\kappa_{10}T_1}{\Omega_7}\frac{1}{|x|^6}+\ldots)dz^2\,;$$

$$m,n=1,\ldots 4\,;\ i,j=1,\ldots 4\,,$$

$$\hat{C}^{(2)}_{0\sigma} = \frac{2}{3}\frac{\kappa_6 Q_1}{\sqrt{2}\Omega_4}\frac{1}{|y|^2}+\ldots\,. \tag{5.1}$$

This solution describes a string wrapped on the z-direction, and exhibits an $SO(1,1)\times SO(4)\times SO(4)\times U(1)$ symmetry. As we did in the previous sections we can interpret this solution as an M1-brane located at the origin of the z-circle, and find the expression for the corresponding solution in the uncompactified case:

$$\begin{aligned} d\hat{s}^2_{M1} &= (1-\frac{5}{21}\frac{\hat{\kappa}_{11}\hat{T}_1}{\Omega_8}\frac{1}{|x|^7}+\ldots)(-dt^2+d\sigma^2)+ \\ &+(1+\frac{1}{21}\frac{\hat{\kappa}_{11}\hat{T}_1}{\Omega_8}\frac{1}{|x|^7}+\ldots)\delta_{mn}dy^m dy^n + \\ &+(1-\frac{2}{21}\frac{\hat{\kappa}_{11}\hat{T}_1}{\Omega_8}\frac{1}{|x|^7}+\ldots)g_{ij}dx^i dx^j + (1+\frac{4}{21}\frac{\hat{\kappa}_{11}\hat{T}_1}{\Omega_8}\frac{1}{|x|^7}+\ldots)dz^2\,. \end{aligned} \tag{5.2}$$

Here Ω_8 is the area of the unit 8-sphere surrounding the string, and we have used $\hat{\kappa}_{11} = \kappa_{10}\,(2\pi R_z)^{1/2}$, $\hat{T}_1 = T_1\,\hat{\kappa}_{11}/\kappa_{10}$. $\hat{C}^{(2)}$ remains the same since it lives in the twisted sector. This solution however does not exhibit the full $SO(1,1)\times SO(4)\times SO(5)$ symmetry of M-theory projected out by $\Omega_\rho I_5$ in the presence of a 1-brane. This symmetry is only recovered if the transverse metric g_{ij} is chosen as:

$$g_{ij} = (1+\frac{2}{7}\frac{\hat{\kappa}_{11}\hat{T}_1}{\Omega_8}\frac{1}{|x|^7}+\ldots)\delta_{ij}\,. \tag{5.3}$$

Therefore, we have found a symmetry-based argument that allows to fix the components of the transverse metric, which remained otherwise undetermined in the boundary state formalism [12]. The key point for this derivation is that when the non-BPS D1-brane solution is uplifted to M-theory the metric along the eleventh direction is fixed by the value of the ten dimensional dilaton, and this determines in the end the whole transverse metric when we imposse that the uncompactified solution has $SO(1,1) \times SO(4) \times SO(5)$ symmetry.

Finally, the contribution to the supergravity action from the twisted sector is proportional to the action describing an M5-O5 system, which in quadratic approximation reads:

$$\hat{S}_{\text{twisted}} \sim \int d^6\hat{y}\sqrt{|\det\hat{g}|}(\hat{\mathcal{H}}^{(3)})^2 + \ldots \tag{5.4}$$

Here $\hat{\mathcal{H}}^{(3)}$ is the field strength associated to the self-dual 2-form potential of the M5-brane worldvolume, with the self-duality condition impossed at the level of the equations of motion, and the metric is restricted to the position of the orientifold fixed plane.

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